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Utilization of Continuous Measured Wellhead Pressure for Evaluating Reservoir Properties

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ABSTRACT

The study aims at the possible application of continuous measured wellhead pressure and transient wellbore simulator for evaluating reservoir properties. The first step of the programs is to conduct the continuous measurement of fluid flow and pressure at the wellhead. The procedure of obtaining reservoir properties is carried out by giving the measured mass flow rate at the wellhead, wellbore and reservoir data for the specified time length into the simulator. The continuous calculated wellhead pressures then are compared with the respective measured wellhead pressures. In order to get the best matching between calculated and measured wellhead pressure, the reservoir properties, especially the permeability-thickness (kh) are changed to obtain the best reservoir properties (e.g., kh) values. The more measured data and properties are given as input for the simulator, the more accurate will be the calculated results.

1. INTRODUCTION

One of the main tasks of a reservoir engineer during the exploration stage of a geothermal development is to determine the reservoir properties. The common technique of determining the reservoir properties, especially permeability-thickness (kh) is by using well testing (draw-down test, build-up test and/or shut-in test). In order to run the test, expensive equipment is required, such as Kuster gauge, rig, and other sensitive electronic devices. On the other hand, during the exploitation stage, the task of the reservoir engineer is to evaluate well performance which is represented by a deliverability curve. It is obtained by plotting measured wellhead pressures against the respective mass flow rates. In the course of geothermal development for power generation, understanding well performance and evaluating well deliverability are an important task for reservoir engineers. This is because predicting steam discharge rate from wells and evaluating the effects of reservoir conditions provide valuable information for designing the size of the power plant. The possible characteristics of the deliverability curve depend on factors such as the reservoir permeability, reservoir pressure and temperature, gas content, and scaling both in reservoir and/or wellbore.

The measurement of two-phase flow in the production well is still the main problem, especially for the plant that has a lay-out of *multi-well one-separator*. The experiences in Indonesia show that the Tracer Flow Testing (TFT) is one of the techniques applied for that purpose. Usually, the technique is only applied occasionally, i.e. when a peculiar condition is encountered (pers. comm.). Applying this technique for flow rate monitoring purpose may not be feasible due to its high cost. Therefore, the method of continuous measurement of steam-water two-phase flow system is developed.

Besides the flow rate measurement, the wellhead pressure measurement is also necessary. The measured wellhead pressures are plotted against respective mass flow rates to obtain a deliverability curve. Furthermore, both measured parameters may be utilized for other purpose. This study aims to propose the possible utilization of the measured wellhead pressures and the respective mass flow rates to evaluate the reservoir properties during the exploration stage and their possible changes during exploitation stage. The process is performed by combining the results of measurement and the transient wellbore simulator that is initially proposed by Miller (1980).

2. MASS FLOW RATE MEASUREMENT METHODS

As a part of geothermal reservoir management, a regular measurement of wellbore performance parameters such as pressure, mass flow rate and enthalpy at the wellhead during the production stage is required to evaluate the well productivity. This is because as the production stage of the field begins the well performances reflect wellbore and reservoir conditions such as declines of reservoir pressure and temperature or scaling in the wellbore. The measurements are also aimed at evaluating the well output during the exploration stage. An example of a mass flow rate measurement layout is shown in Figure 1. The measurement apparatus consists of pressure sensors, water level sensor and a PC to store the measured data. The data are recorded every second for the pressures upstream of the orifices, the pressure drops at the orifices, the pressures at the separators, and the water level at the weir box.

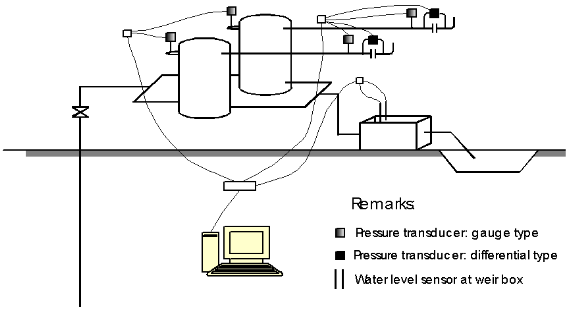

Figure 1: Layout of Measurement.

2.1 Mass Flow Rate Measurement for One-Well One-Separator Scheme

There are two methods for measuring steam and water flow rates; (a) the lip pressure method and (b) the orifice and weir method. In the lip pressure method, the fluid is discharged from the well directly to the atmosphere. The lip pressure is then measured at the extreme end of the discharge pipe using a liquid-filled gauge to damp out pressure fluctuations (Grant et al., 1982). In the latter method, the orifice is used for steam flow rate discharged from the separator and the weir for the water flow rate leaving from the separator (Lindeburg, 1992). The wellhead pressure is usually measured using a Bourdon tube gauge. In order to avoid any thermal and chemical contamination of surface soil and vegetation near the well by discharging fluids to the atmosphere, the orifice and weir method is preferable for flow measurement.

2.1.1 Steam Flow Rate Measurement

The steam flow rate from the separator is calculated based on the standard method. Using an orifice flow meter, the steam flow rate can be determined for known pressure decrease. Figure 2 shows a picture of orifice flow meter.

Figure 2: Arrangement of Devices in Orifice Flow Meter.

The steam flow rate at the separator, Q_{gs} (t/h), can be calculated by Eq. (1) below.

$$Q_{gs} = \alpha\varepsilon\sqrt{2\Delta p\rho_g} \times 3600 \times 0.001 \qquad (1)$$

where α is the flow coefficient (-), ε is the expansion (expansibility) factor of the steam (-), Δp is the pressure difference in the orifice (Pa) and ρ_g is the density of the steam at upstream (kg/m^3).

An example of measured pressure difference in orifice for steam flow rate calculation is presented in Figure 3.

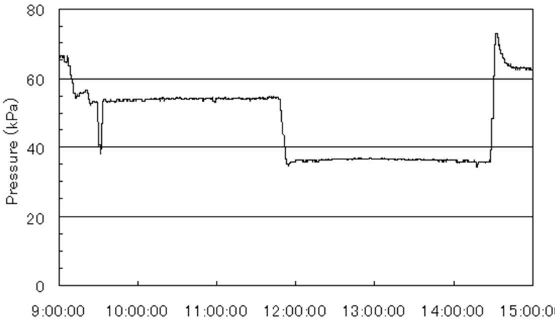

Figure 3: An Example of Measured Pressure Difference in Orifice.

The measured pressure difference shown in Figure 3 was obtained by leaving the well in full open condition during the previous day, then the valve was partly closed at the early time. The curve indicates that the pressure difference decreases. Two steps can be observed. This may suggest that the operators did not make a smooth operation in controlling the valve. The well was then kept flowing without any valve operations. The pressure difference remained relatively constant in this period. Further valve closing operation for the next period resulted in a sharp decrease in measured pressure difference and showed relatively constant values until they suddenly increased to the maximum value due to quick opening of the valve. After reaching the maximum value, the curve decreased quickly after the opening valve operation finished. Then, it decreased gradually and seemed to reach stable conditions as time elapsed.

2.1.2 Water Flow Rate Measurement

The weir box is used for measuring the water flow rate from the separator. Similar to the case of the orifice meter, a standard formula for the weir box is used for calculating water flow rate as shown in Eq. (2) below.

$$Q_v = Kbh^{3/2} \qquad (2)$$

where Q_v, K, b, h are volumetric flow rate of the hot water discharged from the separator through weir box, flow coefficient, width of the rectangular-notch and weir head or the height of a water level measured from the weir, respectively.

To convert the volumetric flow rate of the hot water (Q_v) to the mass flow rate, Q_{lPA} (t/h), Eq. (2) must be multiplied by the density of the hot water at atmospheric pressure, ρ_{lPA} (kg/m^3) as,

$$Q_{lPA} = Kbh^{3/2} \times \rho_{lPA} \times 60 \times 0.001 \qquad (3)$$

However, the flow rate Q_{lPA} is the only part of the total hot water discharged from the separator, because it also flashes at atmospheric condition as Q_{gPA} (t/h). By assuming that the process from the separator to the weir box is isenthalpic, the total hot water flow rate from the separator Q_{ls} (t/h) can be calculated by,

$$Q_{ls}.H_{ls} = Q_{lPA}.H_{lPA} + Q_{gPA}.H_{gPA} \qquad (4)$$

where H_{ls} is the enthalpy of water at the separator pressure, P_s (kJ/kg), H_{lPA} is the enthalpy of water at atmospheric condition (kJ/kg) and H_{gPA} is the enthalpy of steam at atmospheric condition (kJ/kg).

The conservation of mass gives the following correlation,

$$Q_{ls} = Q_{lPA} + Q_{gPA} \qquad (5)$$

By inserting Q_{gPA} into Eq. (5) and Eq. (4) we can calculate the total hot water flow rate from the separator, Q_{ls} as,

$$Q_{ls} = \frac{H_{gPA} - H_{lPA}}{H_{gPA} - H_{ls}} Q_{lPA} \qquad (6)$$

The correlation between the fluid entering and leaving the separator can be expressed by applying the conservation of mass and energy as,

$$Q_{total} = Q_{gw} + Q_{lw} = Q_{gs} + Q_{ls} \qquad (7)$$

and

$$Q_{gw}.H_{gw} + Q_{lw}.H_{lw} = Q_{gs}.H_{gs} + Q_{ls}.H_{ls} \qquad (8)$$

where Q_{total} is the total flow rate at the wellhead (t/h), Q_{gw} is the steam flow rate at the wellhead (t/h), Q_{lw} is the water flow rate at the wellhead (t/h), H_{gw} is the enthalpy of steam at the wellhead (kJ/kg) and H_{lw} is the enthalpy of water at the wellhead (kJ/kg).

In order to make such above calculations, the water level in the weir box must be determined. Figure 4 shows the arrangement for measuring water flow rate in the weir box. The water level is measured using two electrode rods.

An example of water level measurement is shown in Figure 5.

In this sample, the measured water level is measured by using the conventional method (ruler) and electrodes. Applying the measured water level into the standard formula for a rectangular weir box, the water flow rate can be determined as illustrated in Figure 6.

It can be seen that the closing valve causes the decrease in the total mass flow rate and vice versa. The impulse response can be observed during the sudden valve operation as indicated by the second decrease in the mass flow rate. Other observations from the figure are that the fluid flow requires shorter time to stabilize for closing valve operation compared with that for opening valve operation. The duration of valve operation affects the flow stabilization in wellbore. Quick valve operation causes a longer period of stabilization.

2.2 Mass Flow Rate Measurement for Multi-Well One-Separator Scheme

As discussed in Section 1, the measurement of two-phase flow in the case of a multi-well one-separator configuration is still a problem, so it is necessary to develop a system that can be applied for that purpose. In this stage, the development of a two-phase flow measurement method is being carrying out at the laboratory scale. A schematic diagram of the measurement system is shown in Figure 7.

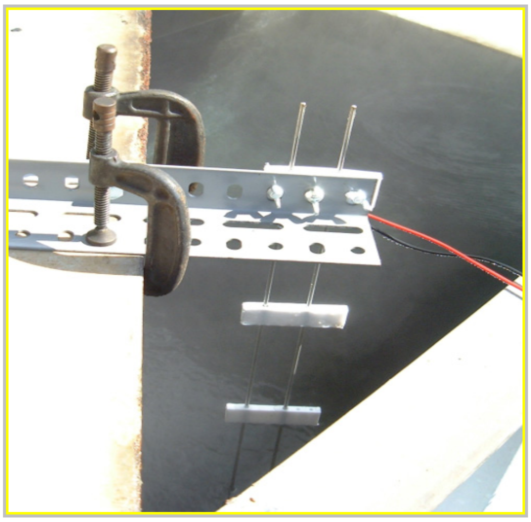

Figure 4: Arrangement of Devices in Weir Box Flow Meter.

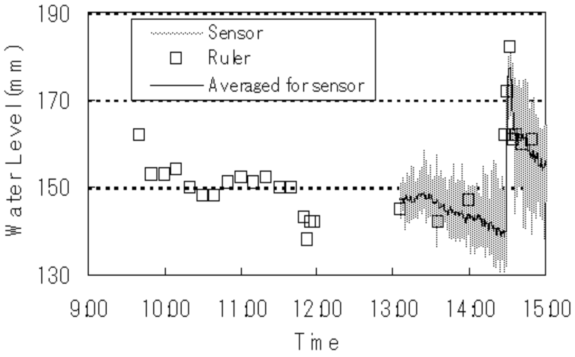

Figure 5: An Example of Measured Water Level.

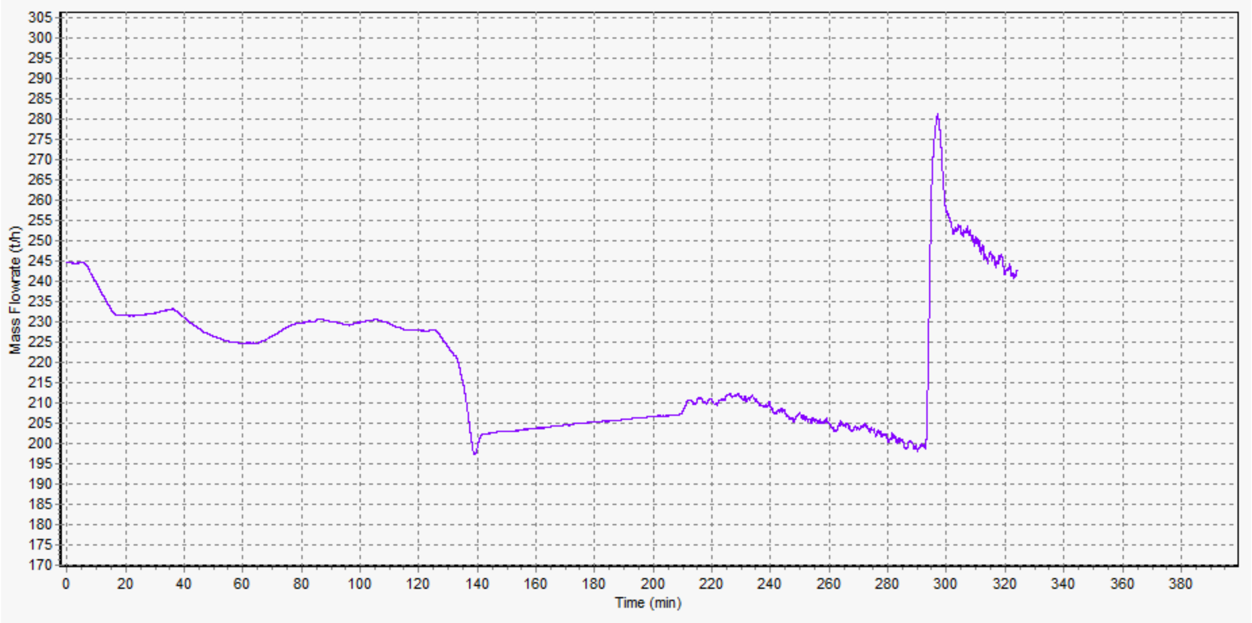

Figure 6: An example of calculated total mass flow rate.

Water is supplied by a centrifugal pump and the flow rate is measured with a venturi meter, while compressed air flow rate is measured with a rotameter or a venturi meter as well.

A modified venturi meter is designed for measuring two-phase air-water flow rate by combining it with a void fraction sensor for measuring the fraction of air in the flow. Measurements are made at atmospheric pressure. Measured parameters are recorded using an analog-to-digital (A/D) converter. The measured data are then stored in a laptop. A picture of the arrangement of the measurement system is shown in Figure 8.

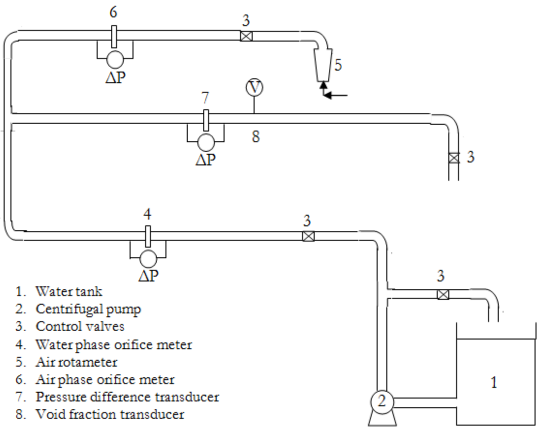

Figure 7: Schematic Diagram of Air-Water Two-Phase Flow System.

3. WELLHEAD PRESSURE MEASUREMENT

Wellhead pressure data is required to determine the fluid properties for mass flow rate calculation. Another purpose of determining the wellhead pressure is to utilize it as matching parameter when evaluating reservoir properties. A typical Bourdon tube gauge is used to measure the wellhead pressure. An example of measured wellhead pressure is shown in Figure 9.

Figure 8: The arrangement of the measurement system.

4. TRANSIENT WELLBORE SIMULATOR

The measured mass flow rate and wellhead pressure that can be used to obtain a deliverability curve, but they may also be utilized for evaluating reservoir properties. The transient wellbore simulator can be used as a tool for that purpose. The governing equations, procedure of calculation, and sample problems of the simulator have been described by Khasani et al. (2005). The front page of the simulator is shown in Figure 10.

The transient wellbore simulator can handle flow problems that cannot be solved by a steady-state wellbore simulator, such as draw-down test, build-up test, and even shut-in test. The simulator is not only useful for analyzing well testing but also for evaluating most problems related to transient flow.

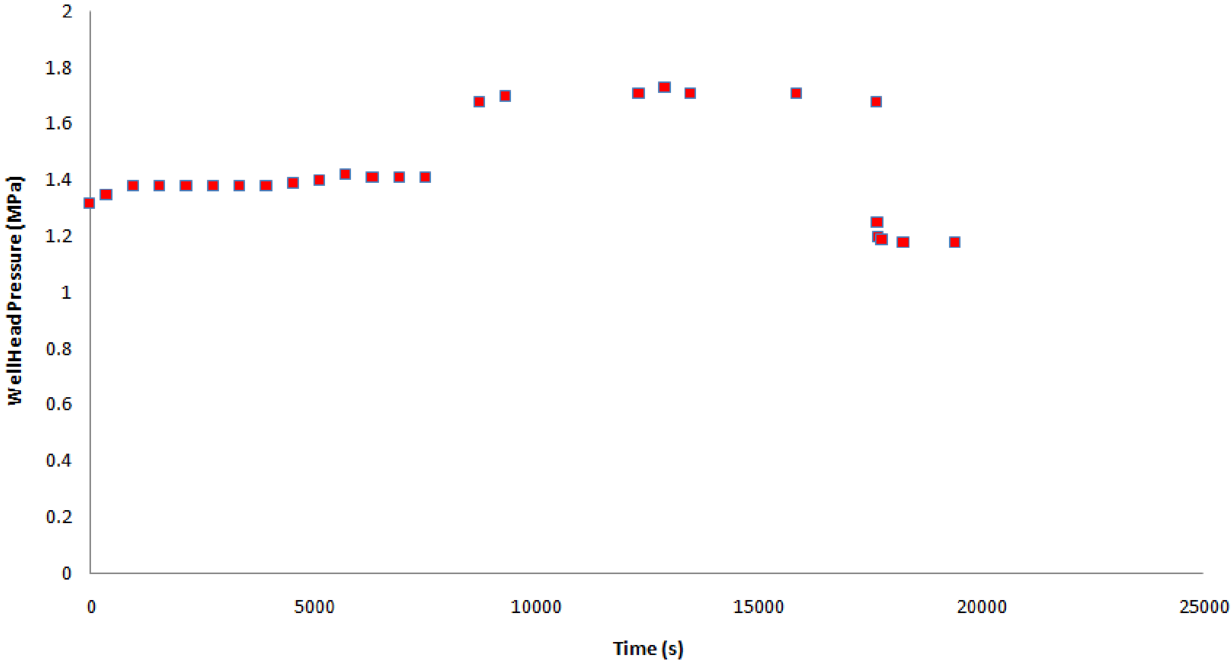

Figure 9: An Example of Measured Wellhead Pressure.

'WELLTRANS'
A Transient Wellbore Simulator
Software that can
handel some case,
such as;
1.Steady State Case.
2.Draw Down Case.
3.Build Up Case.
4.Shut-In Case.
5.Wellbore Storage.
6.Wellbore Scaling.
7.Skin Problem.

Figure 10: Front Page of the Simulator.

In this study, the samples of measured mass flow rate and measured wellhead pressure described in Section 2.1 and Section 3, respectively, are used as input data for the simulator and as matching parameter respectively. The measured mass flow rate is input as a boundary condition at the wellhead. To run the software, it is also necessary to determine other wellbore and reservoir parameters. The typical values for the wellbore and reservoir parameters taken to be as input data in this study are presented in Table 1.

Table 1: Reservoir and wellbore parameters.

Reservoir			Wellbore		
Horizontal extent	:	1500 (m)	Diameter	:	0.2 (m)
Permeability thickness	:	3x10^{-12} (m^3)	Length	:	2000 (m)
Storativity	:	5x10^{-7} (m/Pa)	Roughness	:	4.6x10^{-5} (m)
Thermal diffusivity	:	1x10^{-4} (m^2/s)			
Thermal conductivity	:	1.8 (W/m/^{o}C)			
Initial temperature in reservoir	:	300 (^{o}C)			

Running the software for these parameters, the calculated wellhead pressures can be obtained. The calculated wellhead pressures are then compared with the measured ones. When they are not matched, the parameters in Table 1 are changed depending on which parameters are already known, until the calculated wellhead pressures are matched with the measured ones.

When the software is used for well test analysis, the parameter *kh* is the one that must be changed to seek the best match. The result of the best match for wellhead pressure in this study is presented in Figure 11.

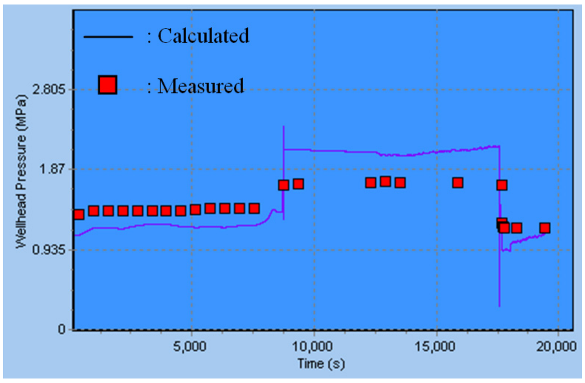

Figure 11: Measured Wellhead Pressure (square) and Calculated Wellhead Pressure (solid line)

An important point is that the more field data that are given as input into the software, the more reliable is the match result. It can be seen that relative good agreement is achieved in tendency for both curves. Impulse responses are also observed for calculated parameters due to quick valve operations. However, this behavior cannot be seen for measured wellhead pressures due to the infrequent measurement.

5. CONCLUSIONS

The integration of the measurement of mass flow rates and wellhead pressures with the transient wellbore simulator can be used for evaluating well performances and reservoir properties.

The reliability of the reservoir properties obtained from this procedure depends on the number of field data given as input into the simulator

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